Broadband heterodyne SIS spectrometer prototype: first results

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1. INTRODUCTION

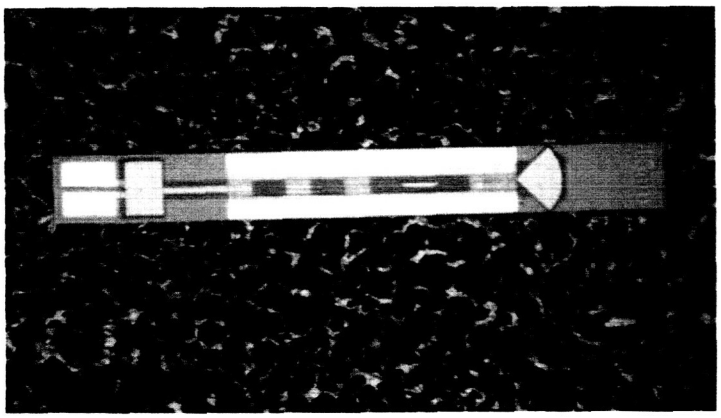
The broadband heterodyne SIS receiver system described elsewhere (reference 1) has been assembled and tested both in the laboratory and during two observing runs on the Cassegrain focus of the 10 meter telescope at the Caltech Submillimeter Observatory on Mauna Kea, Hawaii. Here we present a brief summary of the initial results.

2. FABRICATION AND ASSEMBLY

The SIS mixer chips were fabricated at the JPL Microwave Experiment Systems and Technology Section (reference 2). Figures 1 – 4 are photographs of the chips.

The mixer block containing the RF waveguide, mixer chip, and SIS DC bias board was assembled and combined with a corrugated feed horn, lenses, and superconducting magnet to suppress unwanted Josephson tunneling currents in the SIS junction. A high frequency connector on the mixer block assembly allowed the broadband IF low noise amplifier (LNA) to be closely coupled to the mixer. Illustrations of the complete RF and LNA assembly are included (figures 5 and 6).

The receiver assembly is mounted to the cold plate in a LHe dewar with the feed horn facing downward along the cylindrical dewar axis. A mylar window and a flourogold IR block transmit the RF into the dewar and to the feed horn. A thin mylar beam combiner adds the local oscillator (LO) signal to the RF from the telescope. Once it leaves the dewar the 4 – 18 GHz IF is further amplified and split up into several 4 GHz wide bands which are each down converted to 4 – 8 GHz. These outputs are then presented to WASP II analog autocorrelating spectrometers for analysis. The complete receiver system is shown mounted on the CSO telescope in figures 7 and 8.



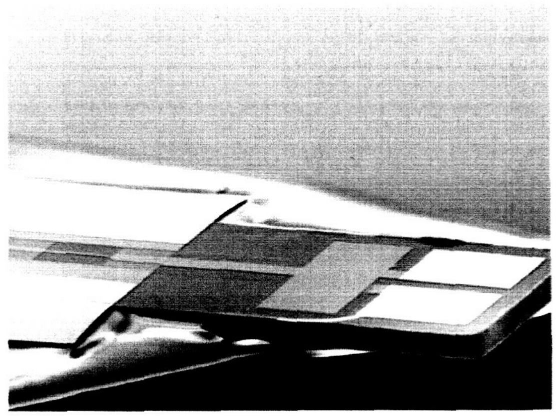
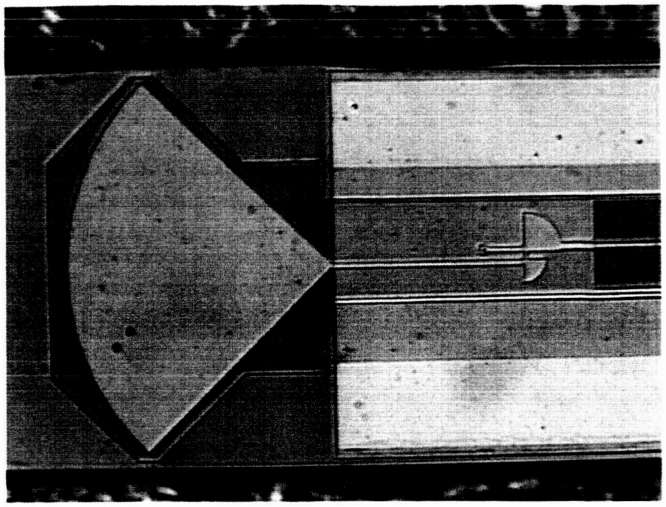


Figure 1 (left): A SIS mixer chip from the first production batch. The silicon substrate dimensions are 1.99 mm × 0.23 mm, 25 microns thick. The "1.5 um" markings denote the SIS junction dimensions on this particular chip; several junction sizes are included on each wafer. The waveguide probe (antenna) is the pie-shaped structure on the right; the rectangular wire bond pads for the IF and DC bias connections are on the left.

Figure 2 (right): Close-up scanning electron micrograph of the wire bond area of a chip from a later production batch which included gold beam leads for ground connections along the long edges of the chip.



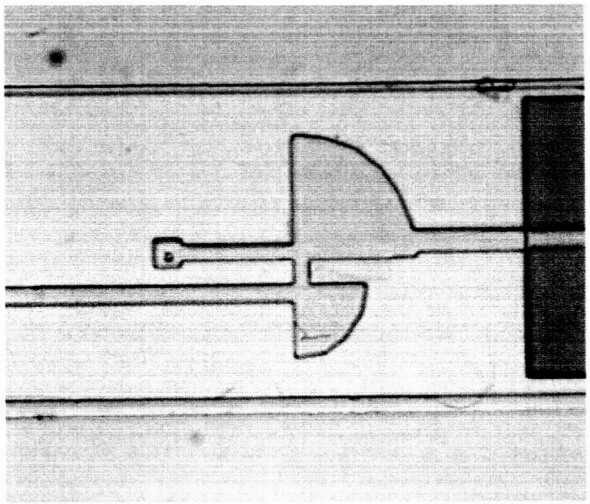


Figure 3 (left): The waveguide probe and RF section of the SIS mixer chip. The waveguide probe has a radius of 150 microns and an opening angle of 90 degrees. The mixer chip is mounted in a channel perpendicular to the RF waveguide axis. The apex of the probe is aligned with the waveguide wall. The probe and wiring are 0.4 micron thick niobium. The brown structure in the photo is the silicon oxide dielectric layer (0.35 micron thick) separating the wiring from a niobium ground plane deposited on the silicon surface. The gold layers provide a wire bonding surface for the ground plane.

Figure 4 (right): Close-up of the RF section and SIS junction on the mixer chip. The SIS junction is the tiny square within the square area to the left of the larger pie-shaped region of the wiring layer (light blue in this photo). The RF signal enters from the left; the IF signal exits to the right.

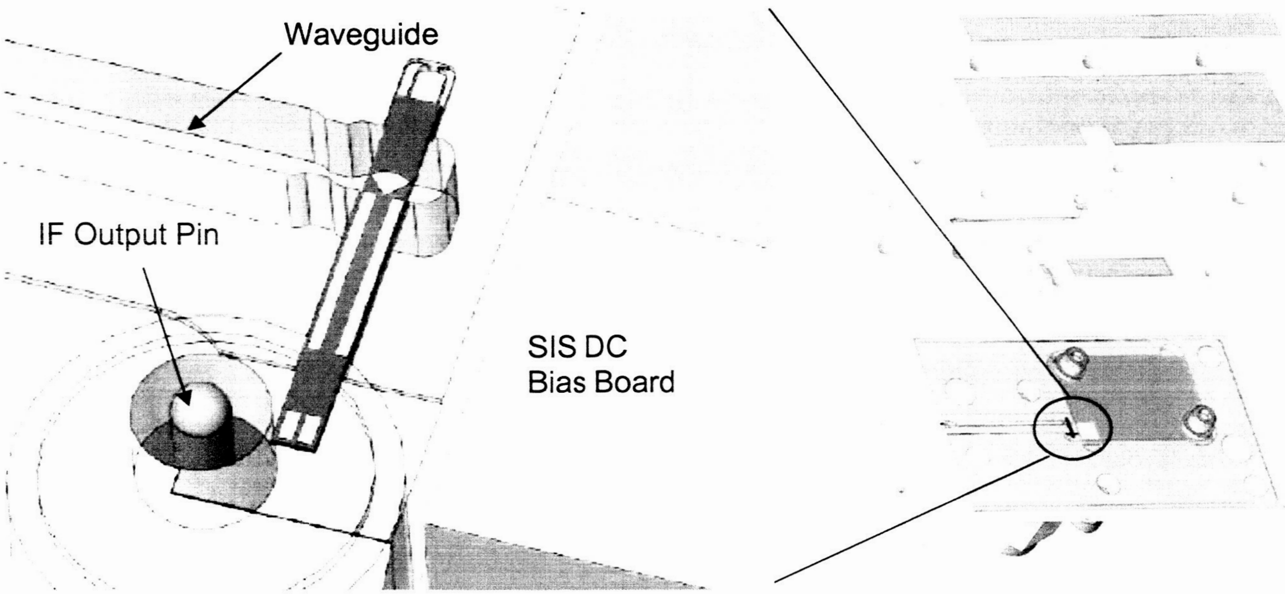


Figure 5: Mixer block assembly. The two halves are machined from brass and then gold plated. The SIS mixer chip is mounted and wire bonded to the IF connector and the SIS bias board, then the two halves of the block are mated.

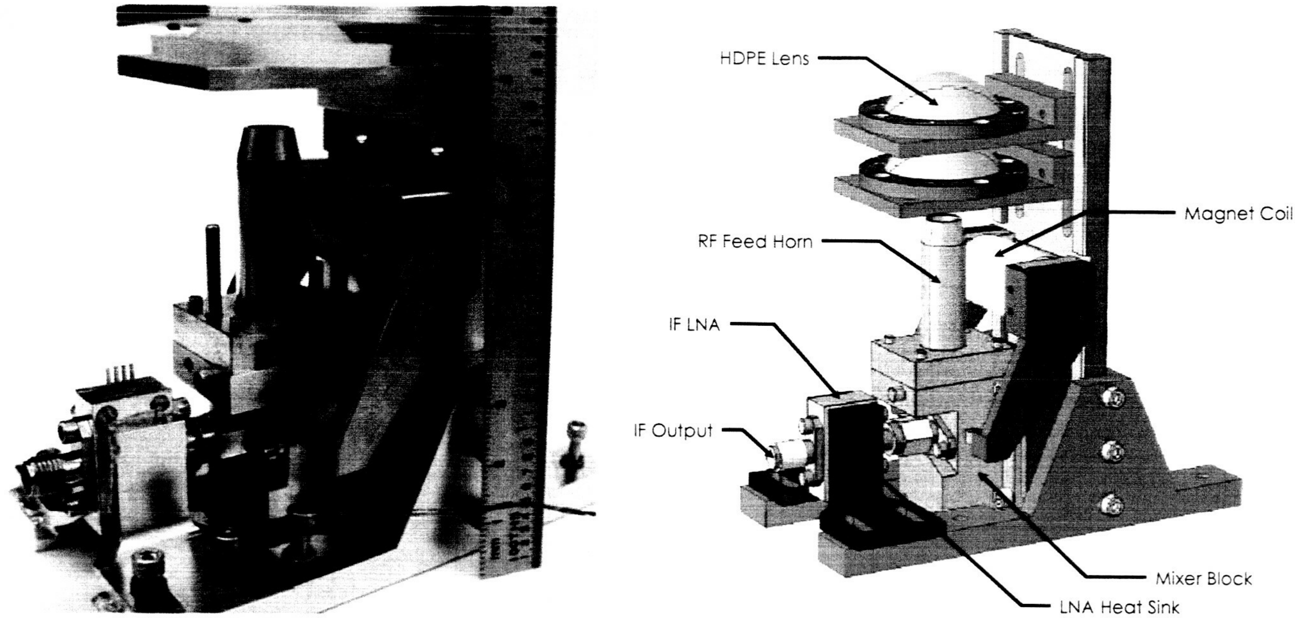
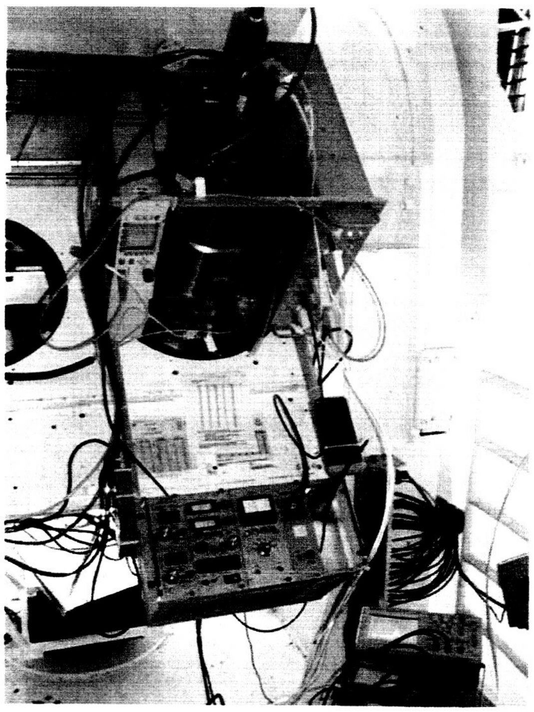


Figure 6: Receiver assembly. The CAD model on the right identifies significant subassemblies found in the photo on the left. This assembly is mounted on the LHe cold plate in the receiver dewar.



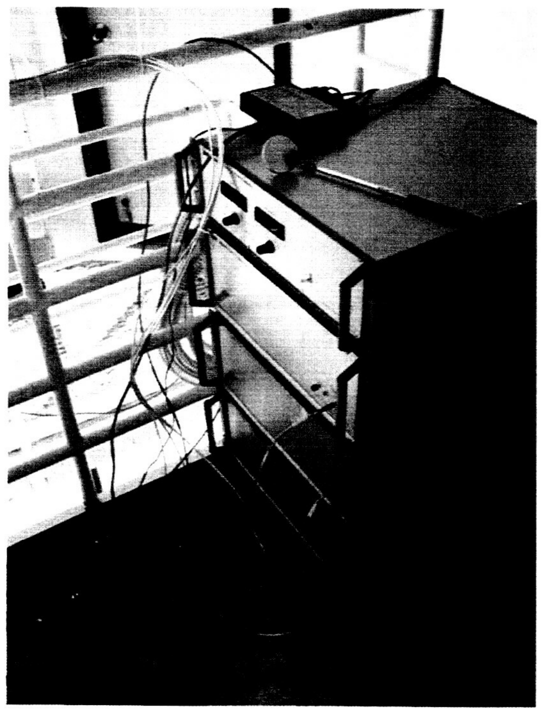


Figure 7 (left): The receiver system mounted on the CSO 10 meter telescope in March 2004. The gold-anodized dewar containing the SIS mixer and LNA is mounted on the telescope Cassegrain focus relay optics. The IF down converter subsystem is mounted just to the right of the dewar; it splits the broadband IF output into four separate bands and down converts each subband to 4-8 GHz. The equipment mounted below the dewar consists of the several power supplies needed to operate the receiver.

Figure 8 (right): The WASP II analog autocorrelation spectrometers. The four 4-18 GHz signals from the receiver are fed to this array of four WASP II units. Each has a bandwidth of 4.25 – 7.75 GHz with 128 channels of spectral resolution. The top unit in the stack of boxes is the power supply for the WASPs.

3. INITIAL RESULTS

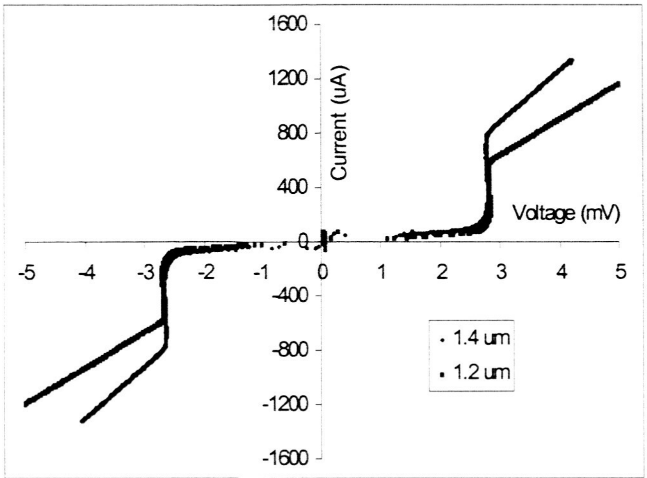


Figure 9: Measured SIS DC IV characteristic curve for 1.2×1.2 micron and 1.4×1.4 micron SIS devices produced at JPL. These are very high critical current density (J_c = 44 KAmp/cm^2) devices; SIS Normal Resistance (R_n) values are 4.3 and 3.0 Ohms, respectively.

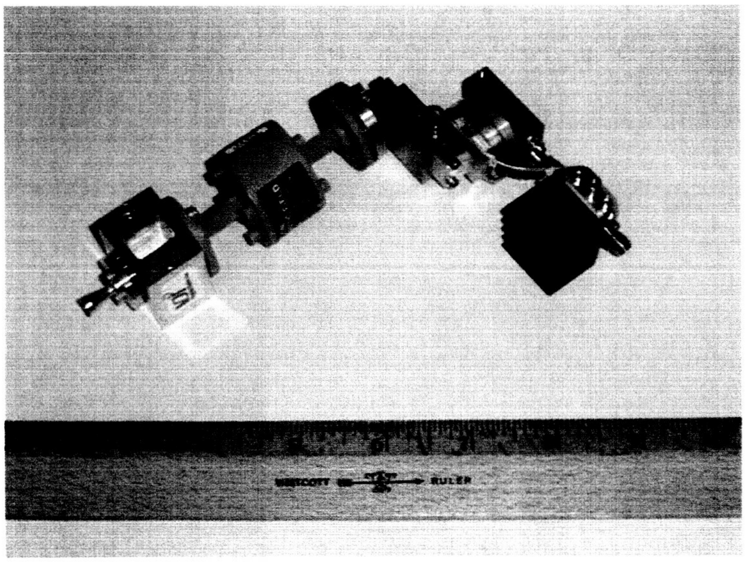


Figure 10: Active amplifier-multiplier chain for the receiver local oscillator (LO). The signal from a microwave generator (13.3 – 18.7 GHz) is input to the connector on the right in the photo. The LO output (200 – 280 GHz) is radiated from the conical horn on the left. The chain has a multiplication factor of 15 and can provide approximately 100 microwatts of output power across the LO band. The chain was custom designed and fabricated by Virginia Diodes, Inc.

The mixer chip was designed for SIS devices with a critical current density (J_c) of 16 KAmp/cm^2, which would result in a normal resistance (R_n) of approximately 8.5 Ohms for a 1.3×1.3 micron SIS junction. The first batch of devices fabricated exhibited a much higher J_c (approx 30 KAmp/cm^2) and, consequently, a rather lower R_n. The second batch had near design J_c junctions. The latest batch, the first production run with beam leads (figure 2), again exhibited very high J_c (44 KAmp/cm^2).

Typical DC current-voltage (IV) curves for the latest batch are also shown (figure 9). The quality of the IV curves for these devices is quite good, so the SIS mixer chip is currently being redesigned to accommodate the higher current density of these devices.

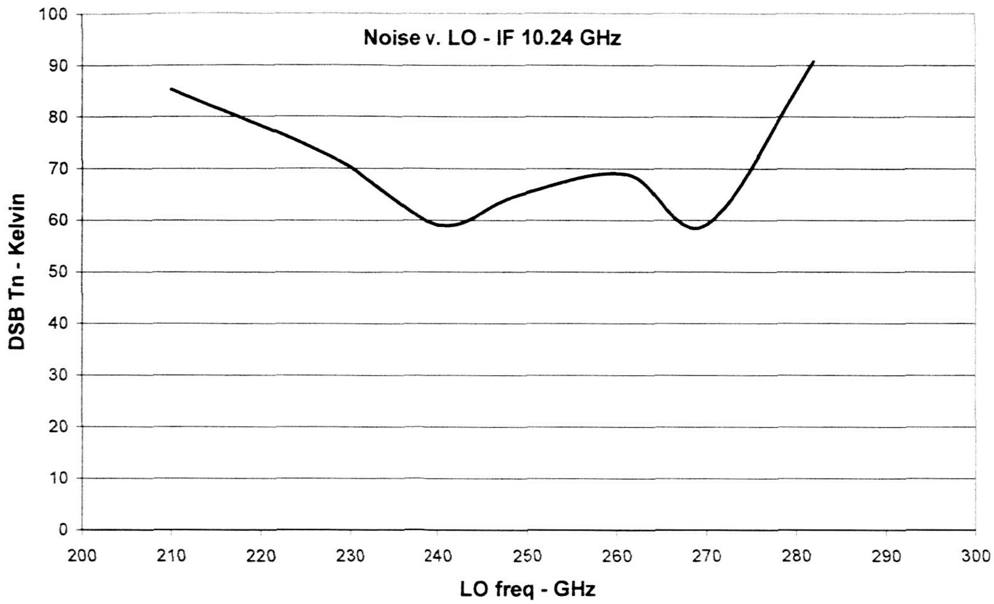


Figure 11: Laboratory measurement of receiver noise temperature v. LO frequency. The measurements were obtained by using the hot-cold load technique and measuring the total receiver output noise power in a 250 MHz bandwidth centered at 10.24 GHz. The IF LNA used was a 4 – 14 GHz design with a measured noise temperature of approximately 4.5 K across the IF band.

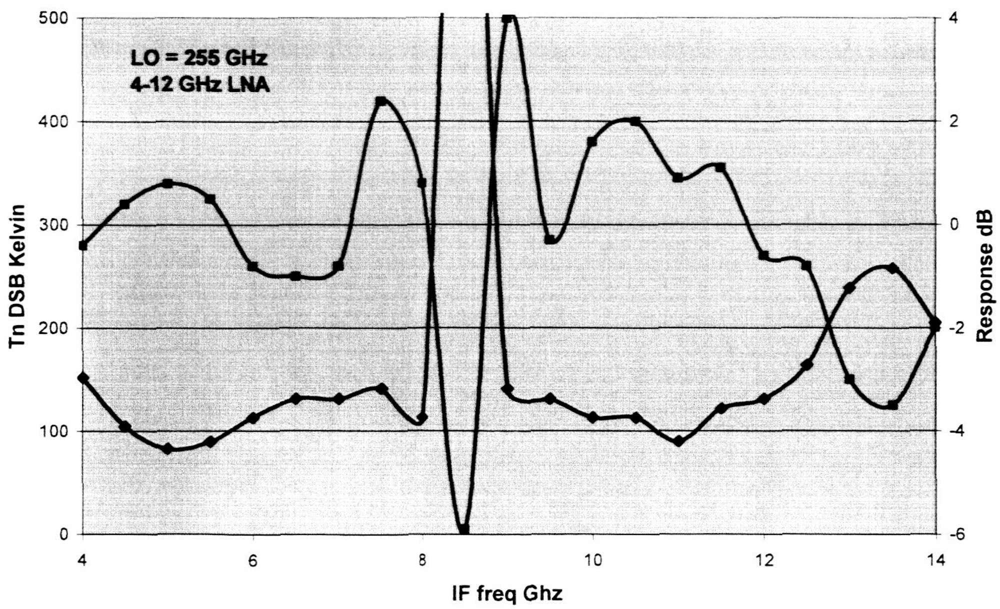


Figure 12: Laboratory measurement of receiver noise temperature v. IF frequency. The measurements were obtained by using the hot-cold load technique and measuring the receiver output noise spectrum using a microwave spectrum analyzer. As in figure 11, the IF LNA used was a 4 – 14 GHz design with a measured noise temperature of approximately 4.5 K across the IF band. The dropout in the response at 8.5 GHz has been determined to be due to a resonance caused by the SIS DC bias board.

Following very brief lab verification tests, the receiver was installed at the CSO for an initial engineering run in August 2003. The Local Oscillator (LO) used for this observing run consisted of an active amplifier-multiplier chain driven by a microwave signal generator. The active amplifier-multiplier chain is pictured in figure 10. First light of the receiver was on August 28. The performance during this first run was quite disappointing, but subsequent laboratory efforts resulted in significant improvements in performance. Lab measurements of receiver noise performance are presented in figures 11 and 12. Following these lab efforts a second observing run was completed in March 2004. A typical result from that run is presented in figure 13.

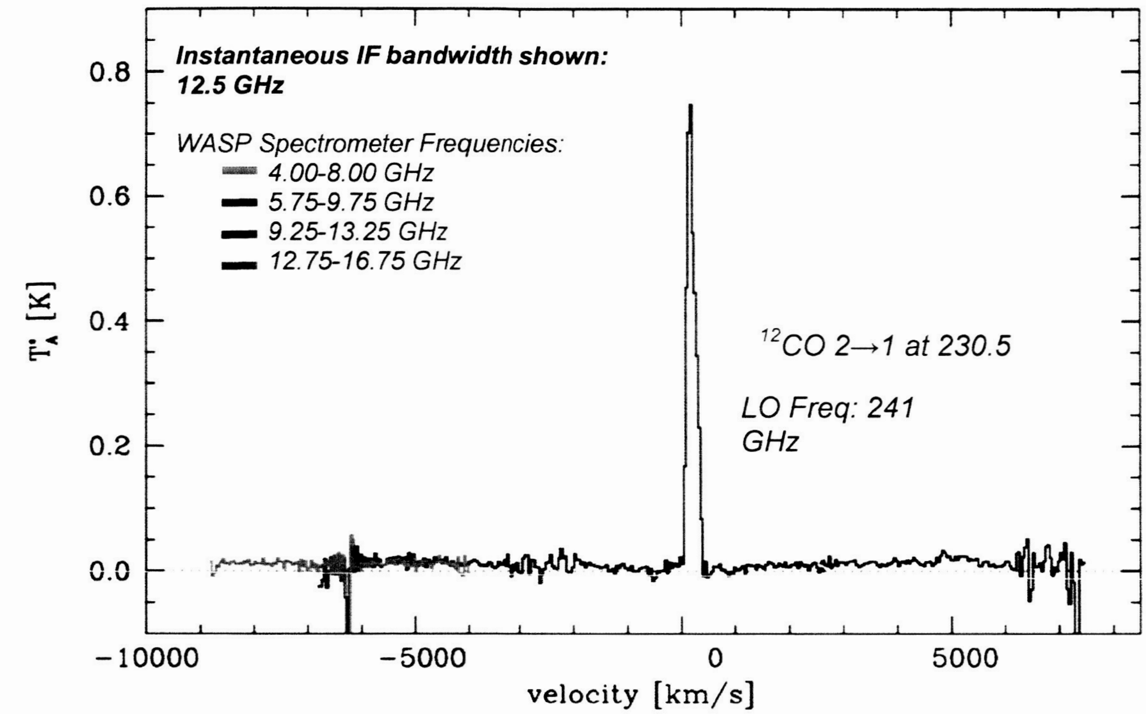


Figure 13: CSO observation of a star-forming region of the galaxy M82 on March 22, 2004. The amount of precipitable water vapor above the Mauna Kea summit was quite high, resulting in a zenith optical depth of 0.21 at 230 GHz. The receiver+telescope+atmosphere system temperature was approximately 500 K. The total observing time was 33 minutes. The receiver configuration included four WASP II spectrometers and is shown in figures 7 and 8.

ACKNOWLEDGEMENTS

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